

LETTER TO THE EDITOR

On stability of the neutron rich Oxygen isotopes

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Abstract. Stability with respect to neutron emission is studied for highly neutron-excessive Oxygen isotopes in the framework of Hartree-Fock-Bogoliubov approach with Skyrme forces Sly4 and Ska. Our calculations show increase of stability around ^{40}O .

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One of the major challenges of nuclear physics is to enlarge the present limits of the chart of the nuclides [1, 2]. The experimental progress during last decade has allowed to reach the proton drip-line up to charge 80 [3, 4]. In contrast, the situation is quite different on the neutron-rich side. Recent studies of neutron-rich light nuclei have shown very exciting issues, that new magic numbers might appear and some disappear when moving to the neutron drip-line [5]. Near the neutron drip-line, the neutron-matter distribution becomes very diffuse and of large size giving rise to "neutron halos" and "neutron skins". These neutron-rich objects have sparked renewed interest in the nuclear structure theory [6, 7].

In this Letter we present our preliminary results in searching for highly neutron-excessive stable light nuclei within Hartree-Fock-Bogoliubov (HFB) approach with Skyrme effective interaction, which has the following form

$$V_{ij} = t_0(1 + x_0 P_\sigma)\delta(\mathbf{r}) + (1/2)t_1(1 + x_1 P_\sigma)[\mathbf{k}'^2\delta(\mathbf{r}) + \delta(\mathbf{r})\mathbf{k}^2] + t_2(1 + x_2 P_\sigma)\mathbf{k}'\delta(\mathbf{r})\mathbf{k} + (1/6)t_3(1 + x_3 P_\sigma)\rho^\alpha(\mathbf{R})\delta(\mathbf{r}) + iW_0[\mathbf{k}' \times \delta(\mathbf{r})\mathbf{k}](\sigma_i + \sigma_j)$$

where $\mathbf{r} = \mathbf{r}_i - \mathbf{r}_j$, $\mathbf{R} = (\mathbf{r}_i + \mathbf{r}_j)/2$, $\mathbf{k} = -i(\vec{\nabla}_i - \vec{\nabla}_j)/2$, $\mathbf{k}' = i(\vec{\nabla}_i - \vec{\nabla}_j)/2$, $P_\sigma = (1 + \sigma_i\sigma_j)/2$. Parameters are given in Table 1.

We have used the set of parameters Ska [8] and compared the results with the most

Table 1. Parameters of the Skyrme forces

Force	t_0	t_1	t_2	t_3	x_0	x_1	x_2	x_3	W_0	α
	MeV fm ³	MeV fm ⁵	MeV fm ⁵	MeV fm ^{3+3α}					MeV fm ⁵	
Sly4	-2488.9	486.82	-546.39	13777.0	0.834	-0.344	-1.0	1.354	123.0	1/6
Ska	-1602.8	570.9	-67.70	8000.0	-.020	0.0	0.0	-0.286	125.0	1/3

widely used set Sly4 [9]. In [10] some of us shown that for deformed nuclei ²⁵Mg and ^{29–31}Si the most satisfactory description of observed spectra comes with the set Ska. Pairing effects were included in the standard way with the pairing constant $G = 19/A$ both for protons and neutrons and restricted to the space of bounded one-particle states.

We carried out the investigations of isotopes ^{4–12}He, ^{14–44}O and ^{38–80}Ca and analyzed how results depend on forces we have used. For isotopes ^{4–12}He our results matched the known ones [11]. For Helium the last stable isotope with respect to two-neutron emission is ⁸He. Comparison with experiment (see the figures) shows that both Ska and Sly4 equally good describe the known experimental data. In our calculations with forces Ska we have found a nucleon stable isotope ⁴⁰O (See Fig. 1). We did not plot the two-neutron separation energy for ⁴⁰O because all its neighboring isotopes are unstable. With forces Sly4 this isotope appears to be unstable with respect to one neutron emission, though the last filled level is close to zero and one can talk

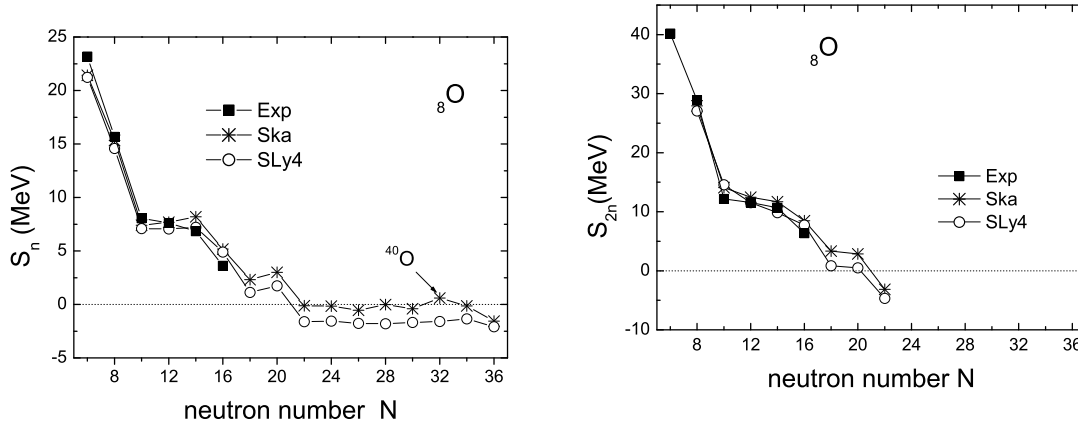


Figure 1. Calculated separation energies of one (S_n) and two (S_{2n}) neutrons for isotopes $^{14-44}\text{O}$ with different choices of Skyrme forces compared to the experimental data [12]. We did not plot the two-neutron separation energy for ^{40}O because all the neighboring isotopes are unstable.

about “quasistability” in this case. From nucleus to nucleus the situation repeats itself, whenever the nucleus is “quasistable” with interactions Ska, then it is “quasistable” with interactions Sly4. In all investigated cases the last filled level for nuclei close to nucleon stability borderline always had a negative parity. And under “quasistable” we mean that this nucleon has a non-zero orbital momentum and the resulting centrifugal barrier prevents the neutron from emission at its low energies.

The obtained data for ^{40}O is given in Table 2. One can see that the values of proton and neutron deformation for ^{40}O are negligibly small.

Table 2. Calculated values of binding energy E , neutron and proton separation energy $S_{p,n}$, root mean square radii $r_{p,n}$ quadrupole moments $Q_{p,n}$ and deformation parameters $\beta_2^{p,n}$ for the stable isotope ^{40}O as calculated with Ska forces.

E	S_n	S_p	r_n	r_p	Q_n	Q_p	β_2^n	β_2^p
MeV	MeV	MeV	fm	fm	$\text{e}^2 \text{ fm}^2$	$\text{e}^2 \text{ fm}^2$		
168.274	0.593	36.822	4.202	2.943	0.031	0.003	0.004	0.004

The maps of proton and neutron distributions in r, z coordinates (incorporating the symmetry of the problem) for ^{40}O and ^{20}O are shown in Fig. 2. One can see although the proton “cloud” is expanding it remains coated with the neutron halo which is about 2 fm thick.

Our preliminary calculations of nearby isotopes showed, that there are stable isotopes around ^{40}O among even-even nuclei, namely $^{40,42,44}\text{Ne}$ with one neutron separation energies are respectively $S_n = 0.13, 0.43, 0.1$ MeV and $^{44,46}\text{Mg}$ with one neutron separation energies $S_n = 0.8, 0.67$ MeV (See Figure 3 for the details). These stable isotopes were also found with Ska forces and except ^{44}Mg they lie beyond the

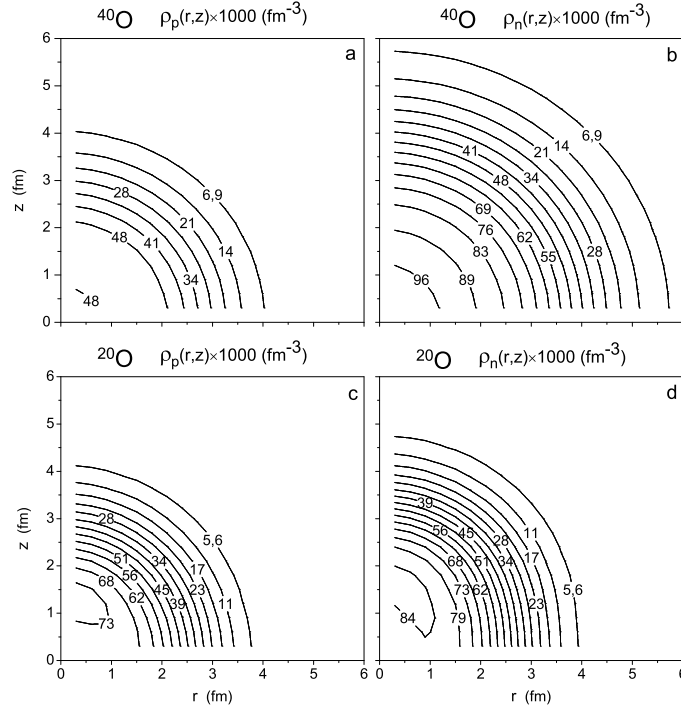


Figure 2. The map of proton ρ_p and neutron ρ_n distributions calculated for ^{40}O (a,b) and for ^{20}O (c,d). The proton “cloud” is expanding with the increasing of the neutron number, but it remains coated with the neutron halo with 2 fm thickness.

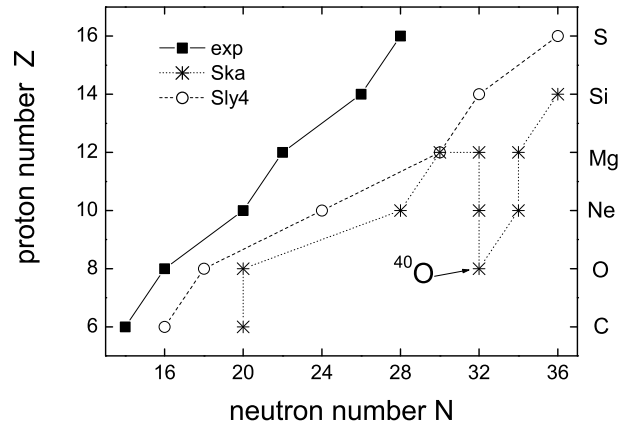


Figure 3. The part of the neutron drip-line. For each value of Z the heaviest stable isotope has been presented for experimental data (Audi 2003 [12]) and Sly4 forces. For the very neutron-rich isotopes HFB calculations with Ska forces shows the different behaviour of the neutron drip-line. See Fig. 1 for the details.

conventional stability valley. We have observed that the usual shell closure at $N=50$ is practically absent for the neutron rich Ca isotopes, and at $N=40$ a new closure appears.

It should be mentioned, that the stability with respect to neutron emission is defined within very narrow range of the binding energy (about 0.5 MeV). Therefore it would be desirable to check this effect with other theoretical models.

Our detailed investigations of the decay properties of the neutron drip-line nuclei in this region of possible stability (isotopes of C,O,N,Mg with the very large neutron excess) are in progress. The results will be published elsewhere.

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